NIOSH HEALTH HAZARD EVALUATION REPORT:

HETA #2000-0410-2891
STN Cushion Company
Thomasville, North Carolina

August 2002

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

HETAB also provides, upon request, technical and consultative assistance to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Josh Harney, Jeffery Hess, and Doug Trout of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Chris Reh, Vince Mortimer, Calvin Cook, Ann Krake, Amber Rogers, Kristin Gwin, Barbara Mackenzie, Edward Hitchcock, and James Kesner. Analytical support was provided by Datachem Laboratories. Desktop publishing was performed by David Butler. Review and preparation for printing were performed by Penny Arthur.

Copies of this report have been sent to employee and management representatives at STN Cushion Co. and the OSHA Regional Office. This report is not copyrighted and may be freely reproduced. Single copies of this report will be available for a period of three years from the date of this report. To expedite your request, include a self-addressed mailing label along with your written request to:

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Highlights of the NIOSH Health Hazard Evaluation

Health Study of Workers Exposed to Bromopropane at STN Cushion Company, Thomasville, North Carolina

NIOSH got a confidential request from workers worried about nerve problems, weakness, dizziness, leg numbness, and headaches they thought were from glue chemicals.

What NIOSH Did

- **We measured air concentrations of 1-bromopropane (1-BP) and 2-bromopropane (2-BP) in the Fabrication area and in other areas of the plant.**
- **We checked the exhaust ventilation in the Fabrication area before and after improvements were made to the spray tables.**
- **We did a medical survey that included a questionnaire, blood and urine testing, neurobehavioral testing, and a female reproductive health study.**

What NIOSH Found

- **Air concentrations of 1-BP and 2-BP decreased in the Fabrication area by almost 2/3 after the ventilation improvements were made.**
- **Workers in the Fabrication area reported dizziness and blurred vision more frequently than those in other areas.**
- **Worker urinary bromine levels corresponded with the airborne 1-BP concentrations.**
- **We could not tell if the exposures to 1-BP at STN were related to health problems among employees.**

What STN Managers Can Do

- **Purchase only 1-BP based solvent containing the lowest possible amount of 2-BP (which is present as a contaminant).**
- **Decrease unused space in each spray booth to make the ventilation work as well as it can.**
- **Keep the Fabrication room emergency exit door and Poly room garage door closed when spraying glue.**
- **Provide gloves [not latex] that protect the skin of Sprayers from 1- & 2-BP.**
- **Change work practices so that employees are not allowed to eat or drink at their workstations.**
- **Share information on potential hazards of working with 1- & 2-BP to all workers who can be exposed.**

What STN Employees Can Do

- **Participate in all hazard communication sessions.**
- **Wear the correct gloves when spraying glue.**
- **Wash hands before eating, drinking, or smoking, and at the end of the day.**
- **Do not eat or drink at your workstation.**
- **If you have health effects that might be related to the workplace you should see a doctor experienced in occupational health issues.**

What To Do For More Information:
We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513-841-4252 and ask for HETA Report #2000-0410-2891

Health Hazard Evaluation Report 2000-0410-2891
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SUMMARY

On August 28, 2000, the National Institute for Occupational Safety and Health (NIOSH) received a confidential request for a health hazard evaluation (HHE) at STN Cushion Company (STN) in Thomasville, North Carolina. The request was submitted by employees concerned about health effects potentially associated with 1-bromopropane (1-BP, also called n-propyl bromide) and 2-bromopropane (2-BP, also called isopropyl bromide) exposures during the spray application of an adhesive. The employees' concerns centered around neuropathy (abnormal nerve function), weakness and numbness in the lower extremities, dizziness, and headaches.

Site visits were conducted in November 2000 (exposure monitoring and informal [confidential] employee interviews), April 2001 (ventilation assessment), and July-August 2001 (medical evaluation and repeat exposure and ventilation evaluations). After April 2001, STN improved the local ventilation in the area of concern based on recommendations made by the NIOSH ventilation engineer. During both exposure assessments, employees were monitored for full-shift 1-BP and 2-BP inhalation exposure. Short-term (15-minute) and ceiling (5-minute) 1-BP and 2-BP inhalation exposure measurements were also collected from the adhesive sprayers (Sprayers). Area air sampling for 1-BP and 2-BP was conducted also. The ventilation assessments included an evaluation of local exhaust ventilation at the workstations (consisting of spray tables and spray booths).

The medical survey, consisting of a questionnaire, a complete blood count, start-of-week and end-of -week urine analysis for bromine, and a battery of neurobehavioral tests, was performed on all employees within the facility who were willing to participate. Additionally, a reproductive study was performed which included all eligible female employees who were willing to participate. The purpose of the medical survey was: 1) to assess whether hematological (blood), neurobehavioral (postural stability and psychomotor ability), and reproductive effects might be associated with 1-BP exposure; 2) to assess whether health effects reported on the questionnaire were associated with 1-BP exposure; and 3) to evaluate urinary bromine levels at the

start and end of the week and compare these results to airborne 1-BP levels (to see if urinary bromine concentration can be used as a biomarker of exposure). The "exposed" population consisted primarily of those employees who worked in the Fabrication area performing spraying activities. The comparison ("less exposed") population consisted of all other employees who worked in the facility.

At the first site visit the mean (average) airborne 1-BP exposure for the Sprayers was 65.9 parts per million (ppm) (range 41.3 to 143.0 ppm). The mean full-shift airborne 2-BP exposure for Sprayers was 0.66 ppm (range 0.33 to 1.35 ppm). At the second site visit, the mean concentration of 1-BP for the Sprayers increased from the first (16.6 ppm) to the third (23.3 ppm) day of sampling, but was lower than the concentration found during the first site visit. Two individual spray booths (Stations #6 and #11) did, however, yield a 3-day average exposure above a recommended level of 25 ppm. The initial ventilation assessment revealed that all of the workstations had exhaust flow rates which were lower than recommended values. Enclosure of spray tables led to improved ventilation at each of the workstations; however, factors were identified which would lead to further improvement in ventilation effectiveness.

Of the 84 individuals employed at STN at the time of the survey, 32 (38%) volunteered to participate in the medical survey. The symptoms most often reported from all participants included: headache (reported by 48%), trouble falling asleep or staying asleep (reported by 28%), dizziness or feeling "off balance" (reported by 25%), and blurred vision (reported by 24%). Two of the symptoms in the questionnaire, blurred vision and dizziness or feeling "off-balance," were significantly more common among the exposed versus the comparison groups. Of the exposed employees, five of six reporting blurry vision and four of six reporting dizziness noted symptom improvement during time away from the work environment.

All of the results for blood indices were within the normal value ranges provided by the testing laboratory; however, because of the small number of blood specimens available for analysis, a statistical determination regarding the blood tests and their relationship to 1-BP exposure could not be made. The start-of-week and end-of-week urine bromine concentrations for the exposed group were both significantly higher than the corresponding values for the comparison group. We found no significant elevation in urine bromine level in the end-of-week urine samples compared to the start-of-week urine samples—in other words, we did not detect an increase in urine bromine from the first urine sample (start-of-week) to the second urine sample (end-of-week). Urinary bromine concentrations were highly correlated to the airborne concentration of 1-BP, and it was concluded that urinary bromine may be a good indicator of 1-BP exposure. A total of 30 participants participated in the neurobehavioral testing. We found no differences in the Postural Stability test results between employees in the exposed and comparison groups. Of the 16 Psychomotor Ability parameters tested, 3 demonstrated a statistically significant difference between the exposed and comparison groups. Specifically, we found indications of increased tremor in the right hand of participants in the exposed group. Although we cannot determine the cause of the tremor observed by our testing, we believe that this unilateral tremor is likely due to muscle fatigue (a known cause of the type of tremor observed), as 1-BP exposure, if sufficient to cause tremor, would likely cause bilateral tremor (tremor on both sides) due to a potential mechanism involving the central nervous system. And lastly, we collected insufficient data among exposed workers in the reproductive evaluation part of the survey to be able to make any comparisons between exposed and comparison workers in that portion of the HHE.

Although we found the Sprayers at STN to have greater exposure to 1-BP than other employees, we are unable to determine if these exposures constitute a health hazard. By enclosing the spray booths in the Fabrication area, STN has dramatically reduced Sprayers' exposures to 1-BP and 2-BP. Because of

symptoms consistent with excessive solvent exposure reported among the exposed workers, concerns raised in other studies, and the lack of definitive information, efforts should continue to minimize 1-BP and 2-BP exposures. Recommendations are provided in this report to assist in this, and include improving the ventilation of spray booths #6 and #11 as well as improving personal protective equipment use.

Keywords: SIC Code 2392 (House furnishing, Except Curtains and Draperies); 1-bromopropane, 1-BP, 2-bromopropane, 2-BP, solvent, neuropathy, neurobehavioral, reproductive.

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INTRODUCTION

On August 28, 2000, the National Institute for Occupational Safety and Health (NIOSH) received a confidential request for a health hazard evaluation (HHE) at STN Cushion Company (STN) in Thomasville, North Carolina. The request was submitted by employees concerned about health effects potentially associated with 1-bromopropane (1-BP, also called n-propyl bromide) and 2-bromopropane (2-BP, or isopropyl bromide) exposures during the spray application of an adhesive. The employees' concerns included neuropathy (abnormal nerve function), weakness and numbness in the lower extremities, dizziness, and headaches. On November 14, 2000, NIOSH investigators conducted an initial site visit at STN which included an exposure assessment of employees applying the adhesive and informal (confidential) interviews to learn more about employee health concerns. A NIOSH ventilation engineer assessed the performance of the existing local exhaust ventilation (LEV) in the Fabrication area on April 18, 2001. Based on recommendations made by NIOSH following the April site visit, STN enclosed the spray tables on four sides to improve the capture efficiency of the local exhaust ventilation, thus creating 'spray booths.' On July 31 to August 2, 2001, NIOSH conducted follow-up exposure monitoring, ventilation assessment, and medical evaluations of workers.

In January 2002, each study participant was sent a copy of all personal test results from the medical evaluation. Results of the industrial hygiene sampling were initially sent to STN and an employee representative in letters dated February 21, 2001 (for the sampling conducted in November 2000), and September 12, 2001 (for sampling conducted July-August 2001). A letter containing a preliminary analysis of the data (including data from biologic samples, neurobehavioral testing, and the questionnaire) was distributed on May 24, 2002. This report consolidates all previous communication, and includes up-to-date conclusions and recommendations.

BACKGROUND

STN manufactures sofa cushions for various furniture companies. Each cushion is assembled by gluing together several pieces of cut flexible foam. Once two pieces of foam are glued together, they are hand-pressed to achieve a proper bond. The adhesive is spray-applied using a compressed air spray gun in the Fabrication room. This room initially contained 13 spray stations having a slotted LEV hood and one down-draft spray table. Following the LEV improvements, the downdraft spray table was discarded, and only 12 spray stations were used. The adhesive is Whisper Spray (Imperial Adhesives, Cincinnati, Ohio), which contains 55% by weight 1-BP. This product also contains 1–5% VM&P naphtha and 1–5% ethyl acetate. In addition, small amounts of 2-BP are usually present in most 1-BP-containing formulations. Occasionally, a water-based spray adhesive (Simalfa® 309, Alfa Adhesives, Inc., North Haledon, New Jersey) that contains no hydrocarbon solvent is used at up to four spray stations. Adjacent to the Fabrication room are the Saw room and the Poly room, neither of which use the spray adhesive.

METHODS

Air Sampling

During the November 2000 exposure assessment, employees in the Fabrication room were monitored for full-shift inhalation exposures to 1- and 2-BP inhalation exposure. Short-term (15-minute) and ceiling (5-minute) 1-BP and 2-BP inhalation exposure measurements were also collected from the Sprayers. In addition, area air sampling for 1- and 2-BP was conducted in the Fabrication, Saw,

and Poly rooms to determine the degree of vapor migration away from the spray tables. For the inhalation exposure measurements, the sampling pumps and sample trains were worn by the employees, and the sample media were placed in the subjects' breathing zones.

Air sampling was conducted using a NIOSH draft sampling and analytical method for 1-BP and 2-BP. In this method, air is drawn through a standard charcoal tube (SKC Anasorb® CSC Lot 2000) at a nominal flowrate of 50–250 milliliters per minute using a calibrated personal sampling pump. After sampling, the charcoal tubes are capped and shipped refrigerated to the analytical laboratory. The front and back sections of the charcoal tubes are placed in glass vials, and each section is desorbed for 30 minutes with 1 milliliter of carbon disulfide. Each sample is analyzed for both 1-BP and 2-BP using gas chromatography with a flame ionization detector.

The 1-BP limit of detection (LOD) and limit of quantification (LOQ) were 0.001 milligram per sample (mg/sample) and 0.004 mg/sample, respectively. The LOD and LOQ for 2-BP are 0.001 and 0.003 mg/sample, respectively. LODs and LOQs are values determined by the analytical procedure used to analyze the samples, and are not dependent on sample volume. Minimum detectable concentrations (MDCs) and minimum quantifiable concentrations (MQCs) are determined by dividing the LODs and LOQs by air sample volumes appropriate for the given set of samples. For this HHE, the average sample volume for a given set of samples was used to calculate these values. MDCs and MQCs for the full-shift exposure measurements can be found at the bottom of Table 1, for the short-term exposure measurements at the bottom of Table 2, for the ceiling exposure measurements at the bottom of Table 3, and for the area air sampling at the bottom of Table 4. While the LODs and LOQs are listed above in terms of mg/sample, the MDCs and MQCs in the tables have been converted to parts per million (ppm) to be consistent with the evaluation criterion.

During the second exposure assessment, full-shift, short-term, and ceiling personal breathing zone (PBZ) samples were again collected from Sprayers. The 1-BP LOD and LOQ for the analytical method used were 0.0007 mg/sample and 0.002 mg/sample, respectively. The LOD and LOQ for 2-BP were 0.0006 and 0.002 mg/sample, respectively. MDCs and MQCs for full-shift, short-term, and ceiling exposure measurements from this portion of exposure monitoring can be found at the bottom of their respective tables (Tables 5, 6, 7) at the end of this report.

Ventilation Assessment

The LEV at the Sprayer's workstations was assessed both before and after the enclosure of the spray tables into spray booths. For the purposes of this report, the spray stations in the Fabrication area will be referred to by a numbering system. As one walks through the plastic curtain from the Saw room into Fabrication and turns to face the wall on the right, Station #1 is the rightmost workstation (nearest the lavatory). Station #2 is immediately to the left of Station #1, and shares its spray booth. Numbering then proceeds with Station #3, immediately to the right of Station #4. Station #4 is to the right of the exit door. Station #5 is on the left side of this exit door, followed in a row along the wall by Stations #6 through #12. At the end of the Fabrication room directly opposite Stations #1 and #2 is Station #12, next to the doorway to the Poly room. Two work- stations that were present during the November 2000 survey were not during the July/August 2001 survey (the downdraft spray table, and a booth along the wall between the Fabrication room door and the lavatory).

Air velocity into the LEV plena was measured with a hot-wire anemometer (TSI® Velocicalc

Plus, model #8360) during both evaluations. During the November 2000 evaluation, five velocities were recorded for each slot, giving 20 readings for each slot hood. Three rows of four measurement points were used for the downdraft table, and 128 readings for each double-station hood. For computation, each 16-grid filter was averaged separately to give 4 values for each single-station hood, and 8 values for each double-station hood. Additionally, air velocity 12-inches above the work surface was measured at 6-inch intervals out from the back wall of the work-station. Some groups of measurements were taken more than once, and the readings were averaged to give one set of values.

The movement of air was also observed using "smoke tubes" (MSA #458481, Mine Safety Appliances Company, Pittsburgh, Pennsylvania). The direction of air movement between the inside and the outside of the building was observed using a smoke tube. The "smoke" was released at the bottom of the door, and observed to note whether it was drawn out of the building or blown in across the floor. If the door was sealed at the bottom to restrict air infiltration, the door was opened slightly to check air flow along the edge.

After the April 2001 site visit, the spray tables were enclosed to become spray booths; each station had its own spray booth, except for #1 & #2 and #9 & #10, which shared spray booths. Measurements of the spray booths were made during the July/August 2001 evaluation. Two of the spray booths (at Stations #3 and #6) are 8' x 44" x 46". Six booths are 10' x 44" x 45"(Station #4, #5, #7, #8, #11, #12). Two spray booths are large enough to accommodate two spray Stations each (#1 & #2, and #9 & #10): 14' x 43" x 45". A thermoanemometer was used to measure the face velocity at evenly distributed points across the mouth of each spray booth where the Sprayer would normally stand. Measurements were collected under two different conditions: 'doors open' and 'doors closed.' This refers either to both the Poly room garage door and Fabrication room outdoor exit door being open or both being closed. These measurements were combined to yield the average face velocity for each spray booth.

Medical Survey

The medical survey, consisting of a questionnaire, a complete blood count, pre- and post-exposure urine analysis for bromine, and a battery of neurobehavioral tests was performed on all employees within the facility who were willing to participate. Additionally, a reproductive study was performed and included all female employees who were willing to participate. The purpose of the medical survey portion of this HHE was: 1) to assess whether objective evidence for hematological (blood), neurobehavioral, and reproductive adverse effects were associated with 1-BP exposure; 2) to assess whether adverse health effects reported on the questionnaire were associated with 1-BP exposure; and 3) to evaluate urinary bromine levels of employees and compare

these results to airborne 1-BP levels (to see if urinary bromine concentration can be used as a biomarker of exposure). The survey was approved by the NIOSH Human Subjects Review Board and was conducted over a three-day period beginning on Monday, July 31, 2001. All employees working at the facility were given the opportunity to enroll in the survey following a 15-minute presentation conducted at STN by NIOSH representatives in the week prior to the survey. In that presentation, the purpose of the study, the tests that would be performed, and the risks and benefits of participation were discussed. Following the presentation, each employee was given the opportunity to enroll in all, portions of, or none of the study. Informed consent was obtained from each employee choosing to participate.

Survey Population

For this survey, the "exposed" population consisted of those employees who worked as Fabrication Sprayers for any part of their work shift, and employees who performed activities other than spraying in the Fabrication area for at least one half of their typical work shift. The comparison ("less exposed") population consisted of all other employees who worked in the facility and who did not perform activities in the Fabrication area or who performed non-spraying activities in the fabrication area for less than one half of their typical work shift.

Questionnaire

On August 1, 2001, each participant was asked to complete a questionnaire. The questionnaire included questions concerning demographic factors (age, gender, etc.), job factors, medical and work history, non-occupational exposures, and symptoms. The questionnaire was self-administered and a NIOSH staff member was available to explain the questions, define medical terms for participants, and check the questionnaire for completeness and errors. For evaluation of the questionnaire, positive responses were determined by a "yes" or "unsure" response to any question. Negative responses were determined by a "no" response.

Blood

Blood samples were analyzed for blood cell counts because the medical literature has suggested that exposure to brominated solvents may be associated with pancytopenia (a decrease in the number of all blood cell types). A 6-milliliter blood sample was collected from each participant during the afternoon of August 2, 2001. Venipuncture was performed by a trained technician following universal precautions for working with blood and blood products.[1] After venipuncture, blood samples were placed on ice and shipped to the NIOSH contract laboratory for analysis. Analysis consisted of determining the white blood cell (WBC) count, red blood cell (RBC) count, and platelet cell (PC) count of each specimen. The counts of these cell types were compared between the exposed and comparison groups.

Urine

Urine specimens were collected early in the morning of July 31 (prior to the work shift—"start-of-week" sample) and in the afternoon of August 2, 2001 (at the end of the work shift—"end-of-week" sample). After collection, urine samples were frozen, stored on ice, and shipped to the NIOSH contract laboratory for analysis. Analysis consisted of measuring the bromine and creatinine concentration of each specimen. At present, there is not an established normal range for the concentration of bromine in human urine and so values obtained were compared between the exposed and comparison groups.

For the purposes of this HHE, pre- or post-exposure urine specimens with a creatinine value outside of the acceptable range (creatinine less than 0.3 grams/liter [g/L] or greater than 3.0 g/L)

were not reported or used for analysis, because they cannot be relied upon to accurately reflect the true body burden of bromine.[2] Urinary bromine levels were not corrected for creatinine concentration. Start-of-week urine bromine concentrations were compared to end-of-week concentrations so that the change over the 3-day period could be determined.

Neurobehavioral Testing

Neurobehavioral testing measures basic psycho-physiological functions (alertness, reaction time, memory, tremor, sensory and motor performance). Two neurobehavioral test types (Postural Stability and Psychomotor Ability) were used in this survey to evaluate the presence of neurologic changes potentially related to 1-BP exposure. Other researchers have used these or similar tests to evaluate neurologic changes due to solvent exposure.[3,4,5,6] Neurobehavioral testing was chosen over electromyography (tests of individual muscle function) because it was felt to be a more sensitive measure of neurological change. Analysis of each test parameter, comparing exposed and comparison groups, was performed to determine if a significant difference exists between the group's performance (between-group analysis).

Postural Stability

Each participant was tested on a microcomputer-controlled force platform using protocols established by NIOSH and the University of Cincinnati.[7,8,9,10] Test conditions were designed to test the three main afferents (variables) responsible for maintaining postural stability (e.g., vision, vestibular perception, and proprioception). After one practice trial, each participant was asked to stand on the force platform while performing each of six different postural maneuvers lasting 30 seconds. For the first maneuver, participants were instructed to remove their shoes and stand still on the platform with arms at their sides focusing on a fixed mark on the wall directly in front of them. The next maneuver required the participant to maintain the same posture but with their eyes closed. These two test maneuvers were then repeated while the participant stood on a 4-inch thick foam pad. The final two test maneuvers required the participant to stand still on one leg with eyes open, but focusing on the fixed mark on the wall was not required. This maneuver was then repeated while standing on the opposite leg. Sway area and sway length were measured during each test. Sway area represents the area within the sway path in square centimeters, and sway length is the length of the sway path in centimeters.

Psychomotor Ability

A commercially available test system (CATSYS®) from Danish Product Development was used to test psychomotor ability.[11] Eight tests were selected to evaluate arm-hand tremor, simple reaction time, and rhythmic finger/hand tapping ability. Test procedures and device characteristics are described in a previous NIOSH publication.[12] The test researcher explained and demonstrated each test to the participant before allowing the individual to perform that test. Participants were allowed to repeat a test only if they did not start the test within 5 seconds of when the equipment was activated and the researcher indicated the subject should begin, or the computer determined that there were insufficient responses during the test period to calculate an accurate test result. The system had a volume control which was set to maximum volume so that any subject with hearing difficulties could clearly hear the audible "clicks" produced for certain tests.

Tremor was measured using a tremor pen. Each subject held the pen first in the right hand and then in the left hand (referred to as tremor pen right and tremor pen left), similar to an ordinary pencil, in front of their chest with their elbow bent at 90 degrees, and the forearm away from their body

for a prescribed period of time while the equipment recorded movements of the pen. Each hand was tested twice with results from the second test retained for data analysis. Tremor intensity (i.e., amplitude), the root-mean square of accelerations recorded in the 0.9 Hertz (Hz) to 15.0 Hz band during a 16-second test, and center frequency (i.e., average frequency of accelerations at the mid-point of the energy band) were the principal measurements used for analysis.

Simple auditory reaction time was assessed via a hand-held thumb switch (referred to as reaction time). The participant was instructed to hold the switch in his or her dominant hand and press the thumb switch every time he or she heard the system produce an audible 'click.' The test computer produced each 'click' at random intervals for a total of 30 seconds. Mean response latency (milliseconds) is the measurement used for analysis.

The rhythmic finger tapping was assessed via a shock sensor. Each participant was instructed to use his or her dominant hand for the test. The palmar surface of the wrist rested on the table surface in front of the shock sensor and the participant was instructed not to elevate the wrist off the table surface during the test. When the test began the participant was to tap their index finger on the sensor once for each audible 'click' produced by the test computer. The first test used a long interval between each 'click' (referred to as slow rhythmic frequency finger tap). The second test used a short interval between each 'click' (referred to as fast rhythmic frequency finger tap). The last test used a crescendo, decreasing interval, between each 'click' (referred to as maximum frequency finger tap). Rhythmic hand tapping was assessed using the same sensor. The participant was instructed to tap their dominant hand on the sensor alternately using the supinated (hand extended with palm surface up) then pronated (hand extended with palm surface down) surface of their dominant hand with each 'click' produced by the test computer. The first test used a long interval between each 'click' (referred to as slow pronation/supination rhythmic frequency). The second test used a crescendo, decreasing interval, between each 'click' (referred to as maximum frequency pronation/supination).

Reproductive Study

The reproductive portion of this HHE was designed to evaluate changes in women's hormonal cycle that might be related to 1-BP exposure. A reproductive study of males was not conducted at STN primarily because there is only one male employee considered "exposed" at STN. The study included a questionnaire, first morning urine samples (5–10 milliliters) collected daily for one complete menstrual cycle (or, in the event of amenorrhea, for at least 42 days), and daily diary documentation during the urine collection phase. The questionnaire for this portion of the study included questions primarily pertaining to reproductive health history. Urine samples were analyzed (at the NIOSH Reproductive Endocrinology Laboratory) for luteinizing hormone (LH), follicle stimulating hormone (FSH), and the primary urinary metabolites of estrogen (estrone 3-glucuronide [E,3G]) and progesterone (pregnanediol 3-glucuronide [Pd3G]). The daily diary was used to document sample collection, presence of menses, and use of medications or birth control.

At the time that the questionnaire was administered, NIOSH investigators provided each participant with a collection kit and detailed verbal and written instructions on the urine collection process. Participants were instructed to store urine samples in their own freezer (at home) during the collection process; vials contained 7% glycerol to prevent freeze-induced activity loss of LH and FSH.

Women who volunteered in the female reproductive health portion of the study (Phase II) were paid $100 for participation.

Statistical Analysis

Statistical analyses for this survey was performed using SPSS for Windows Release 11.0.1 (SPSS Inc., Chicago, IL). A p-value of 0.05 and 95% confidence intervals (95% CI) which excluded the value one were used to determine statistical significance. The odds ratio (OR), a measure of the strength of association between reported symptoms and exposure, was used to evaluate questionnaire responses. The OR represents the odds of an outcome in the "exposed" group relative to the odds in the "unexposed" group. An OR of one means there is no association between the outcome and "exposure." An OR of greater than one indicates that there is evidence of an association. For example, an OR of two would mean that a person in the "exposed" group may have two times the odds of reporting the outcome than a person in the "unexposed" group.

EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increases the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[13] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®),[14] and (3) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[15] Employers are encouraged to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criteria.

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91-596, sec. 5(a)(1)]. Thus, employers should understand that not all hazardous chemicals have specific OSHA exposure limits such as PELs and short-term exposure limits (STELs). An employer is still required by OSHA to protect their employees from hazards, even in the absence of a specific OSHA PEL.

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended STEL or ceiling values which are intended to supplement

the TWA where there are recognized toxic effects from higher exposures over the short-term.

1-Bromopropane and 2-Bromopropane

Laboratory studies of the toxicology of 1-BP have shown that excessive exposure of animals to 1-BP can lead to reproductive and neurologic effects. The limited published information concerning occupational exposure to 1-BP suggests neurologic and reproductive effects in humans. A review of the scientific literature relevant to occupational exposure to 1-BP is presented in the Appendix.

Currently, there are no NIOSH, ACGIH, or OSHA exposure evaluation criteria for 1-BP. Albemarle Corporation (a manufacturer of 1-BP) has recommended an occupational exposure guideline for 1-BP, based on the initial, unaudited data from a two-generation reproductive study in rats.[16] In that study, young male and female rats received a daily 6-hour inhalation exposure to a known concentration of 1-BP for a minimum of 70 days. After this period, the animals were paired for mating, and the daily exposures continued through the 14-day mating period, and through day 20 of gestation. No litters were observed in the 750 parts per million (ppm) exposure group, and a significant decrease was observed in the number and size of litters in the 500 ppm exposure group. A slight (insignificant) decrease was observed in the mean number of pups born and live pups per litter for the 250 ppm exposure group. Based on these results and a 10-fold safety factor, Albemarle set their 1-BP recommended exposure guideline at 25 ppm as an 8-hour TWA exposure.[17]

The South Korea Ministry of Labor is the only government agency to develop an occupational exposure level (OEL) for 2-BP. In 1998, the Ministry issued a 2-BP OEL of 1 ppm as an 8-hour TWA.[18] This standard is based on a limited number of workplace epidemiological studies and toxicological (animal) studies which found that 2-BP exposure produces reproductive effects in both males (low sperm count) and females (ovarian dysfunction), and also affects the hematopoietic (blood forming) system.[19,20,21,22,23,24,25]

Local Exhaust Ventilation

The velocity of air at any point in front of a hood necessary to overcome opposing air currents and to capture the contaminated air at that point by causing it to flow into the hood is called the capture velocity.[26] The velocity with which the contaminant is released and other factors will determine the appropriate value for the capture velocity. For the adhesive spraying operation at STN, the contaminant dispersion would at least be characterized as "low velocity release into moderately still air," for which the range of recommended capture velocities is 100–200 ft/min. For some workstations, the contaminant dispersion might be better characterized as "active generation," for which the range of recommended capture velocities is 200–500 ft/min.[27]

The lower end of these ranges is acceptable when the air currents at the point of capture are minimal or favorable to capture, the contaminant(s) is (are) of low toxicity or of nuisance value only, the production rate is low or intermittent, or the hood is large enough to cover the work area and contain the air mass moving toward the hood. However, when disturbing air currents are present, the contaminant(s) is (are) highly toxic, production rates/contaminant-source-substance usage is high and/or the hood is small and capable of providing local control only, the upper end of the range is recommended.[27]

For the adhesive spraying operation at STN, although disturbing room air currents were not prevalent, neither were they minimal or favorable

to capture. Although not classifiable as highly toxic, bromopropane toxicity is unknown (and was not classified as low toxicity). Production was fairly steady, and the hood openings did not extend the full width of the workstations. This indicates that the capture velocity should be at least 150 ft/min and, for some workstations, as high as 350 ft/min.

The capture velocity at the furthest point of contaminant release in front of a hood is related to the required exhaust air flow by the equation[28]

$$Q = 0.75v(10x^2 + A)$$

Where: Q = the required exhaust air flow in cubic feet per minute (cfm)
v = the capture velocity in feet per minute (ft/min)
x = the distance in feet from the hood face to the furthest point of contaminant release
and A = the hood face opening area in square feet (ft^2).[29]

The opening area is the width of the opening or slots multiplied by the distance from the bottom of the lowest slot or opening edge to the top of the highest slot or opening edge.[28]

For the adhesive spraying operations in front of the back-draft hoods, the furthest point of contaminant release would be approximately 3 ft in front of the back wall of the workstations. For either: 1) the single 26-inch wide opening (7 inches high), or 2) the four 30-inch wide slots (1 inch high, spaced 6 inches apart), the exhaust flow rate should be at least 10,000 cubic feet per minute (CFM). For the down-draft table with a 21-inch long opening, 12 inches wide, the exhaust flow rate at 18 inches above the surface should be at least 2700 CFM.

RESULTS

Air Sampling

November 2000—before enclosure of spray tables

A total of 14 full-shift 1-BP and 2-BP exposure measurements were collected from workers in the Fabrication room (Table 1). Twelve of these measurements were from Sprayers, and two were from floaters. The mean (average) 1-BP air concentration for the Sprayers was 65.9 ppm, ranging from 41.3 to 143.0 ppm. All 12 of the Sprayers had exposures which exceeded the Albemarle exposure guideline of 25 ppm. The 1-BP concentrations for the two floaters were 8.7 and 19.4 ppm.

The mean full-shift 2-BP concentration for Sprayers was 0.66 ppm, ranging from 0.33 to 1.35 ppm. One of these concentrations exceeded the South Korean OEL of 1 ppm. The 2-BP concentrations for the floaters were 0.19 and 0.28 ppm.

Random short-term (15-minute) and ceiling (5-minute) exposure measurements were obtained in order to characterize acute 1-BP and 2-BP exposures in Sprayers. Nine short-term exposure measurements were obtained from Sprayers (Table 2). The short-term 1-BP concentrations ranged from 33.7 to 173.9 ppm, and the short-term 2-BP concentrations ranged from 0.30 to 1.56 ppm.

Eleven ceiling exposure measurements were also obtained from the Sprayers (Table 3). The 1-BP ceiling concentrations ranged from 39.5 to 151.9 ppm, and the 2-BP concentrations ranged from 0.37 to 1.13 ppm.

Finally, full-shift area air sampling was conducted in the Fabrication, Saw, and Poly rooms to determine the 1-BP and 2-BP room concentrations, and to determine the extent to which these compounds are migrating to adjacent areas. These data are shown in Table 4. The 1-BP and 2-BP concentrations in the Fabrication room were 7.2 and 0.11 ppm respectively. In addition, the 1-BP concentrations in the Saw and Poly rooms were 7.7 and 1.7 ppm, and the 2-BP concentrations were 0.20 and 0.05 ppm respectively.

July/August 2001—after enclosure of spray tables

Cushion production reportedly was slightly below normal at the beginning of this survey (July 31, 2001), but increased roughly 20% each of the next two days. Results from full-shift air sampling done each day are listed in Table 5. The mean concentration of 1-BP for the Sprayers increased from the first (16.6 ppm) to the third (23.3 ppm) day of sampling, but was lower than the concentration found during the first site visit; the mean 2-BP concentration did not vary widely. For each day of sampling, the mean concentration of the Sprayers as a group was below the exposure limit suggested by Albemarle. Two individual spray booths (Stations #6 and #11) did, however, yield a 3-day average exposure above 25 ppm for the workers at those particular booths.

Table 6 lists short-term (15 minute) exposures of the Sprayers. Concentrations for 1-BP ranged from 0.2 ppm, for the Sprayer at booth #11, who did not spray much during this 15 minute period, to 56 ppm. 2-BP short-term concentrations ranged from trace (between 0.04-0.13 ppm) to 0.4 ppm. Table 7 lists the Sprayers' 5-minute ceiling exposures. Concentrations ranged from 'not detected' (below 0.14 ppm) to 38 ppm for 1-BP, and from 'not detected' (below 0.12 ppm) to 0.5 ppm for 2-BP.

Air sampling results for non-Sprayers are listed in Table 8. Several PBZ and general area (GA) samples were collected each day. 1-BP concentrations ranged from 0.01 ppm (GA samples collected outside the building) to 6.1 ppm (GA sample collected on the saw room I-beam closest to the doorway to the assembly area). 2-BP concentrations were 0.1 ppm or less in all samples. These results indicate that at least some solvent vapor appears to be present in areas of the plant away from the Fabrication area.

Local Exhaust Ventilation

Spray Table Evaluation—November 2000—before enclosure of spray tables

The capture velocity 3 ft in front of the thirteen back-draft hoods in the Fabrication area ranged from 6 ft/min to 73 ft/min, and the capture velocity 18 inches above the down-draft table (station # 6) was 26 ft/min. (See Table 9) The calculated exhaust flow rates for each hood (also listed in Table 9) ranged from 230 CFM to 1545 CFM. All of the values are less than the recommended values (as discussed in the Evaluation Criteria section).

Consistent with the low exhaust flow rates and capture velocities, air-flow visualization revealed that the hoods performed only marginally well with air flowing toward the back of the workstations at some, but not all, locations across the face of each work- station. Moreover, except for the hood with the greatest air flow, for which all smoke released at the front edge of the workstation was "captured," contaminants released at one (or both) edge(s) of each of the other workstations would drift lazily away into the workroom. The external foam filter covering some of the openings did not seem to greatly affect the flow of air in front of the hoods.

Observed work practices revealed that pieces of foam for seat cushions were stacked in front of the slot hoods at some workstations, preventing adhesive spraying in the region of the workstation where exhaust ventilation would be most effective. Some large pieces blocked the local exhaust ventilation slots while being sprayed with adhesive, restricting the effectiveness of the local exhaust ventilation.

Spray Booth Evaluation—July/August 2001—after enclosure of spray tables

Table 10 shows the average capture velocity measured at each spray booth under two sets of conditions: 'doors open' and 'doors closed.' Capture velocities at the spray booths ranged from 18 ft/min (Station #12) to 70 ft/min (Stations #1 & #2) with the doors closed. Operating with the doors closed did not have a clear effect on the capture velocity of all the spray hoods compared to when the doors were open.

Medical Survey

Questionnaire

Of the 84 individuals employed at STN at the time of the survey, 32 (38%) volunteered to participate in the medical survey. A total of 30 (36% of the 84) employees completed the study questionnaire; included in this number were 12 (92%) of 13 employees in the exposed group, and 18 (25%) of 71 in the comparison group. Table 11 lists selected characteristics of participating employees who completed the questionnaire. Of note, the employees in the groups were primarily women, and were of similar age. Employees in the exposed group had a mean length of employment at STN of 13 years, compared to 21 years for employees in the comparison group. Two (17%) in the exposed group and 7 (39%) in the comparison group provided positive answers to the question concerning exposure (occupationally or through other activities) to other substances of concern (defined in the questionnaire as arsenic, mercury, lead, cadmium, solvents, or pesticides). The two subjects from the exposed group responding positively to this question had marked "don't know" as their response and did not give any further detail concerning their exposure in the explanation section.

Regarding data collected concerning work practices, 92% of exposed workers responded they always wore some type of protective clothing (such as an apron) while working; our observation of work practices revealed that the aprons worn did not protect the arms from contact with solvents. Two (17%) exposed and 1 (6%) comparison subject responded that they smoked "sometimes" or "rarely" in the work area. Sixteen percent of the exposed group washed their hands "always" or "sometimes" before smoking and after performing work activities. All participants reported that they washed their hands before eating or chewing gum after performing work activities.

Table 12 presents data concerning reported symptoms by exposure status (exposed versus comparison group). The symptoms most often reported from all participants included: headache (reported by 48%), trouble falling asleep or staying asleep (reported by 28%), dizziness or feeling "off balance" (reported by 25%), and blurred vision (reported by 24%). The data in Table 12 reveal that two of the symptoms in the questionnaire had a statistically significant odds ratio between the exposed and comparison groups (indicating that those two symptoms were reported more commonly among the exposed employees versus the comparison group). The exposed group reported 16 times the odds of experiencing blurred vision (95% CI 1.6 - 162), and 15 times the odds of experiencing dizziness or a feeling of being "off balance" (95% CI 1.5 - 153) within the last 30

days. None of the odds ratios for the remaining symptoms were statistically significantly elevated. Of the exposed employees, five of six reporting blurry vision and four of six reporting dizziness noted symptom improvement during time away from the work environment. Two of six reporting blurry vision and two of six reporting dizziness reported experiencing that symptom on the day the questionnaire was administered.

Blood

A total of 24 (29% of the 84 total employees) participants agreed to have their blood drawn. Within this group, venipuncture was unsuccessful on three participants, and 9 of the samples collected clotted before arriving at the lab, making these specimens unsuitable for analysis. Consequently, only 3 (23%) of 13 exposed, and 9 (13%) of 71 comparison blood samples were available for analysis. All of the results for WBC, CBC, and PC were within the normal value range provided by the testing laboratory.[30] No statistically significant differences were detected between the means of the blood indices for the exposed and comparison groups.

Urine

A total of 23 (27% of 84) participants provided start-of-week and end-of-week urine specimens. Within this group 4 participants were unable to provide a start-of-week specimen and 2 participants were unable to provide an end-of-week specimen. One specimen was excluded from analysis because it had a creatinine concentration that fell outside the acceptable range for this analysis (indicating that it cannot be relied upon to accurately reflect the true body burden of bromine). Consequently, there were 6 (46%) of 13 exposed and 10 (14%) of 71 comparison paired urine specimens available for analysis.

Results of the urine bromine statistical analyses are in Table 13. The start-of-week and end-of-week urine bromine concentrations for the exposed group were both statistically significantly higher than the corresponding values for the comparison group ($p < 0.01$). We found no significant elevation in urine bromine level in the end-of-week urine samples compared to the start-of-week urine samples—in other words, we did not detect an increase in urine bromine from the first urine sample (start-of-week) to the second urine sample (end-of-week). Regression analysis of both start-of-week and end-of-week urinary bromine concentrations versus personal breathing zone air concentrations of 1-BP demonstrated a statistically significant positive correlation.

Neurobehavioral Testing

A total of 30 participants participated in the neurobehavioral testing portion of the study; included in this number were 12 (92%) of 13 exposed, and 18 (25%) of 71 comparison employees.

Postural Stability Testing

Not all study subjects were able to complete the entire Postural Stability test battery. Six subjects (one from the exposed group) were unable to stand on either their right or left leg for a long enough period of time to complete both of the last two tests. Three subjects (all in the comparison group) were unable to stand for a long enough period of time on either their right or left leg to complete one of the last two tests. We found no differences in the Postural Stability test results between employees in the exposed and comparison groups.

Psychomotor Ability Testing

Results for each of the Psychomotor Ability tests can be found in Table 14. Every employee taking part in the neurobehavioral testing completed the

entire Psychomotor Ability test battery. Of the 16 parameters tested, 3 demonstrated a statistically significant difference between the exposed and comparison groups. In each case the mean test value was higher (demonstrating increased effect) in the exposed group. These three parameters included right tremor pen intensity, right tremor pen frequency, and slow rhythmic frequency finger tap standard deviation.

Regression analysis of each of these variables (right tremor pen frequency, right tremor pen intensity, and standard deviation of slow rhythmic frequency finger tap) against PBZ air concentrations of 1-BP demonstrated a statistically significant positive correlation only for right tremor pen frequency. No statistically significant correlation was demonstrated for right tremor pen frequency when compared against urine bromine concentrations, and neither of the other two variables mentioned above (right tremor pen intensity or slow rhythmic frequency finger tap standard deviation) demonstrated a statistically significant correlation with any of the measures of exposure.

Reproductive Evaluation

Ten women agreed to participate in the reproductive portion of the evaluation. Four of the women did not finish the study or provide urine samples or diaries. Only one of the women who completed the study was in the exposed group (working in the Fabrication area); all the others were in the comparison (less exposed) group. Additionally, upon analysis of the urine specimens, it became apparent that the one exposed worker did not follow the correct procedure for urine collection. Therefore, none of the data we collected for this portion of the survey was able to be compared between exposed and comparison workers, and we will not be able to make any determinations of potential female reproductive effects of 1-BP exposure in this HHE. The results of these menstrual cycle function analyses have been provided to the participants.

DISCUSSION

Exposure Survey

The 1-BP exposure data from the November 2000 sampling indicated that all 12 Sprayers had full-shift 1-BP exposures above the Albemarle exposure guideline of 25 ppm. Considering these findings, and the results of our ventilation assessment, the NIOSH investigators concluded that the LEV system was not adequately removing or controlling the 1-BP vapors. Additionally, the area air sampling data indicated that low concentrations of 1-BP and 2-BP were migrating to nearby areas. Follow-up air sampling in July/August 2001, revealed decreased mean 1-BP exposure of Sprayers by over 60% (22.5 ppm vs. 62.1 ppm). 2-BP exposures also decreased over 60% (0.2 ppm vs. 0.62 ppm). However, measurements at two spray booths (Station #6 and #11) revealed concentrations of 1-BP that remained above the Albemarle exposure guideline. Our observation of work practices at those stations indicates that individual work habits of Sprayers (e.g., the amount of adhesive sprayed on each cushion) are likely important factors contributing to the higher exposures observed at those two spray booths.

Of note, some work practices which might have been expected to affect measured PBZ exposures appeared not to have a measurable impact in our survey. For example, some Sprayers stayed at their workstations during their morning, lunch, and/or afternoon breaks, while others left the Fabrication room and went outdoors or to other areas of the building. Additionally, Station #3, #6, #8, and #12 were set up to use a water-based spray adhesive (not containing 1-BP), which if used extensively during the day could result in decreased BP exposures for workers. However,

the water-based spray adhesive was used only sporadically during this survey, and had no obvious effect on BP exposures received by the Sprayers using it.

Some Sprayers used natural latex rubber gloves to prevent adhesive from getting on their skin. While this may be effective in keeping adhesive off their skin, it does not protect against dermal exposure to 1-BP and 2-BP. At least one manufacturer of BP products recommends using gloves made of flexible laminates, such as Viton®.[31]

Ventilation Assessment

Whenever there is a potential for a hazardous exposure in a workplace, traditional industrial hygiene practice dictates that the following hierarchy of controls, in decreasing order of desirability and effectiveness, be implemented to protect worker health:

1. Elimination of the toxic substance from the workplace.
2. Substitution of the toxic substance with a less toxic substance.
3. Installation of engineering controls designed to reduce exposure.
4. Use of administrative controls to reduce exposure.
5. Use of personal protective equipment to reduce exposure.

In many instances, it is not possible to eliminate or substitute a chemical or material from a production process without altering the integrity of the desired product. Thus, many strategies for reducing hazardous exposures center on the use of engineering controls such as process isolation and/or local exhaust ventilation. At STN, 1-BP vapors have largely been controlled using the spray booths at each workstation, with each booth discharging the captured air and vapors outside of the building. While spray booth operation as of the August 2001 site visit was an improvement over conditions observed during the NIOSH survey of November 2000, two things can be done to further improve LEV effectiveness. With the Poly room garage door and Fabrication room outdoor exit door closed, the plastic curtain separating the Assembly room from the Saw room began flapping due to the dramatic increase in airflow through this doorway into the Fabrication room. This did not occur with the doors open. Keeping the doors closed is therefore more likely to minimize the migration of solvent vapors into the Saw room and rest of the building. Also, there appeared to be a large amount of unused space in several of the spray booths. Minimizing the unused volume within each spray booth, while not decreasing the work space so much that cushion assembly is hindered, will result in an increase in face velocity, without changing the exhaust fan speed, duct size, etc.

Medical Survey

Questionnaire

Blurry vision and dizziness were reported more commonly among the workers exposed to 1-BP compared to those who were less exposed. Additionally, five of the six workers reporting blurry vision, and four of the six reporting dizziness, reported that the symptoms resolved after leaving the work environment. Previous studies have demonstrated vision changes related to solvent exposure,[32,33] and other studies have found that chronic mixed solvent exposure can cause an increase in the subjective symptom of dizziness.[34,35] One of the two published case reports concerning occupational 1-BP exposure did mention that individuals reported experiencing dizziness during exposure, but neither of the published reports noted exposed persons reporting blurry vision.[20,21] The blurry vision and dizziness reported in our questionnaire, however, are nonspecific symptoms which could have many potential causes, and the low participation rate in

the study makes it difficult to determine whether these findings are generalizable to the overall study population.

Hematological Effects

Our evaluation detected no association between occupational exposure to 1-BP and changes in hematological indices; however, because of the small number of blood specimens available for analysis, we cannot make a definite determination regarding the blood test results and their relationship to 1-BP exposure.

Urinary Bromine

Our survey demonstrated that airborne 1-BP concentrations were correlated with both start-of-week and end-of-week urine bromine concentrations. This finding is consistent with the findings of a previous 1-BP biological monitoring study.[36] However, we did not demonstrate an increase in urine bromine concentrations in the end-of-week sample compared to the start-of-week sample for individuals or the group as a whole. Possible explanations for this finding are: 1) bodily elimination of bromine via the kidneys may be slow, so that exposure to airborne 1-BP over a 3-day period (the time over which we collected our samples) does not affect urinary bromine concentration at a level we can detect; and 2) exposure to 1-BP in the time period prior to our survey may have been greater than that during our survey, leading to declining urine bromine levels (reflecting the decreased exposure).

Neurobehavioral

Psychomotor Ability Testing

In our survey the neurobehavioral test parameters for frequency and intensity of tremor in the right hand were increased in the exposed group; right hand tremor frequency alone was correlated with airborne 1-BP concentrations. Many different types of occupational exposures, including exposure to solvents, have been associated with tremor.[37] In general, tremors related to toxic exposures are thought to be due to effects of the toxins on the central nervous system and not the peripheral nervous system.[38,39] If 1-BP were to have the same type of central mechanism, it is not likely that overexposure to 1-BP would cause a unilateral tremor (tremor of one hand/arm and not the other), which was the type of tremor our testing detected. Our findings of increased unilateral tremor among the exposed workers could be related to muscle fatigue of the right hand and arm. Holding an adhesive spray gun (weighing 1 to 1.5 pounds) in one hand consistently while performing job activities could fatigue the muscles of that hand, arm and shoulder. Because the exposed group was tested late in the work day (after performing job activities for 4–6 hours), it is likely that some level of hand or arm fatigue was present in these individuals. Muscle fatigue can cause a mild tremor, which the tremor pen test is sensitive enough to detect, and the pen tremor test is unable to distinguish between muscle fatigue tremor and neurological based tremor of the hand and arm. We did not collect information concerning participants' dominant hand, or which hand they preferred to use when holding the adhesive spray gun, so we are unable to directly address that issue.

The time frame over which our tests were administered makes it impossible for us to distinguish whether the tremor detected might be due to an acute or chronic condition or effect. It

is possible that, in some cases, the tremor we noted is a result of a chronic neurological condition unrelated to current work activities or exposures (and which may have existed prior to work at STN). Therefore, for all the reasons listed above, we are not able to determine the cause(s) of the tremor we observed with our medical testing.

A third parameter, the standard deviation of slow rhythmic frequency finger tap, was also increased in the exposed group versus the comparison group. However, because the corresponding test parameter, slow rhythmic frequency finger tap mean, was not increased in the exposed group, it is likely that the finding related to the standard deviation is not meaningful.

Postural Stability Testing

The postural sway studies we conducted failed to demonstrate any significant difference in balance between test groups despite the fact that the symptom of dizziness was reported more frequently among the exposed group. One possible reason for this could be that the "dizziness" reported in the questionnaire actually represented symptoms consistent with "lightheadedness," rather than vertigo or altered balance. Additionally, the questionnaire addressed symptoms occurring within the 30 days prior to our evaluation. If the symptom was transient (not occurring on the day of testing) the reported symptoms would not necessarily correlate with objective testing.

Survey Limitations

The ability of this survey to detect any potential associations between 1-BP exposure and health effects was limited by several factors in addition to those limitations listed above. The first limitation was the small number of participants, decreasing our ability to detect differences between the exposed and comparison groups if they in fact existed. A second limitation was the low participation rate, which could lead to a selection bias (persons who participated may not be representative of all the workers). A third limitation involves the fact that the 1-BP exposures at STN were moderate in comparison to other facilities in the U.S., particularly after ventilation improvements were made at the plant.

CONCLUSIONS

Although we found the Sprayers at STN to have greater exposure to 1-BP than other employees doing different work, we are unable to determine if these exposures constitute a health hazard. Further investigation of potential health effects related to occupational exposure to 1-BP is needed before any definitive conclusions can be made. Nevertheless, because of symptoms reported in our survey which are consistent with known effects of solvents, and because of concerns raised in other studies, until more definitive information is available we believe that every reasonable effort should be taken to minimize 1-BP exposures. By enclosing the spray booths in the Fabrication area, STN has dramatically reduced Sprayers' exposures to 1-BP and 2-BP, as evidenced by reductions in full-shift, short-term, and ceiling exposures measured before and after LEV improvements were made. Improvements in the ventilation of spray booths #6 and #11 are needed to bring those workstations up to the level of the remainder of the stations. We also found that the latex gloves used by Sprayers do not protect them from dermal exposure to 1- or 2-BP. Regarding our survey of urinary bromine concentrations, we found that urinary bromine concentrations were highly correlated to the airborne concentration of 1-BP to which individuals were occupationally exposed at this facility. We conclude that urinary bromine may be a good indicator of 1-BP exposure, however, further research is needed to confirm our findings.

RECOMMENDATIONS

The following recommendations are made to assist in minimizing worker exposure to 1-BP (and 2-BP).

1) STN should continue investigating the use of non-hydrocarbon solvent adhesives. This may require experimentation with the flow of cushion parts within Fabrication, since the water-based adhesives do not 'set up' as quickly as does the current adhesive most frequently used at STN.

2) When buying a 1-BP based adhesive, STN should choose the one with the lowest amount of residual 2-BP.

3) STN should provide Fabrication Sprayers with gloves that protect against dermal exposure to 1-BP and 2-BP; materials to consider include gloves and aprons made from flexible laminates (e.g., Viton™, 4H™ (PE/EVAL), Silver Shield™).

4) The Fabrication room outdoor exit and the Poly room garage doors should remain closed so that vapor migration into other areas of the building is minimized.

5) The unused volume in each spray booth should be decreased as much as possible to optimize the current ventilation. This should increase the LEV capture velocity and further lower worker exposures.

6) Sprayers, and other employees using chemicals, should not eat or drink at their workstations.

7) The findings of our medical survey do not by themselves indicate that medical follow-up is needed for any specific employees or groups of employees. However, employees who are experiencing health effects potentially related to the workplace should be evaluated by a healthcare provider who has experience with occupational or environmental health issues.

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Table 1
Full-Shift PBZ air sampling results for 1- and 2-BP
STN Cushion Company
Thomasville, North Carolina
HETA 2000-0410-2891
November 14, 2000

Job Title	Department	Sample Time (min.)	Sample Volume (L)	Concentration, ppm, 8-hr. TWA	
				1-BP	2-BP
Sprayer	Fabrication	498	25.0	41.3*	0.5*
Sprayer	Fabrication	496	25.0	143.0*	1.4*
Sprayer	Fabrication	495	25.0	74.7*	0.8*
Sprayer	Fabrication	296	15.0	29.4	0.2
Sprayer	Fabrication	494	24.9	73.4*	0.7*
Sprayer	Fabrication	487	24.5	48.6*	0.5*
Sprayer	Fabrication	492	24.9	75.8*	0.8*
Sprayer	Fabrication	494	24.9	78.3*	0.7*
Sprayer	Fabrication	491	24.8	51.3*	0.6*
Part Time	Fabrication	350	17.5	34.7	0.4
Part Time	Fabrication	282	14.1	32.3	0.3
Part Time	Fabrication	350	17.5	41.3	0.5
Floater	Fabrication	345	17.3	6.3	0.1
Floater	Fabrication	349	17.5	14.1	0.2
Recommended exposure guideline				**25**	**1**
Minimum Detectable Concentration (MDC)				**0.01**	**0.01**
Minimum Quantifiable Concentration (MQC)				**0.03**	**0.02**

** For sampling periods longer than 8 hrs., the average concentrations for the time sampled is given.*

Table 2
Short Term (15-minute) PBZ air sampling results for 1- and 2-BP
STN Cushion Company
Thomasville, North Carolina
HETA 2000-0410-2891
November 14, 2000

Job Title	Department	Sample Time (min)	Sample Volume (L)	Concentration, ppm	
				1-BP	2-BP
Sprayer	Fabrication	17	3.4	173.9	1.56
Sprayer	Fabrication	17	3.4	110.1	1.04
Sprayer	Fabrication	16	3.2	55.4	0.54
Sprayer	Fabrication	16	3.2	92.3	0.98
Sprayer	Fabrication	15	3.0	72.2	0.62
Sprayer	Fabrication	15	3.0	33.7	0.38
Sprayer	Fabrication	15	3.0	42.6	0.3
Sprayer	Fabrication	15	3.0	65.6	0.54
Sprayer	Fabrication	15	3.0	138.5	1.05
Minimum Detectable Concentration (MDC)				**0.06**	**0.06**
Minimum Quantifiable Concentration (MQC)				**0.23**	**0.18**

Table 3
Ceiling (5-minute) PBZ air sampling results for 1- and 2-BP
STN Cushion Company
Thomasville, North Carolina
HETA 2000-0410-2891
November 14, 2000

Job Title	Department	Sample Time (min)	Sample Volume (L)	Concentration, ppm	
				1-BP	2-BP
Sprayer	Fabrication	5	1.2	151.9	1.13
Sprayer	Fabrication	6	1.6	51.9	0.49
Sprayer	Fabrication	6	1.5	44.3	0.59
Sprayer	Fabrication	5	1.2	114.3	1.13
Sprayer	Fabrication	5	1.3	70	0.81
Sprayer	Fabrication	6	1.5	102.8	1.08
Sprayer	Fabrication	6	1.6	48.7	0.63
Sprayer	Fabrication	6	1.6	39.5	0.37
Sprayer	Fabrication	6	1.6	72.2	0.8
Sprayer	Fabrication	5	1.2	49.7	0.56
Sprayer	Fabrication	5	1.5	67.6	0.69
Minimum Detectable Concentration (MDC)				**0.12**	**0.12**
Minimum Quantifiable Concentration (MQC)				**0.5**	**0.37**

Table 4
Full-Shift Area Air Sampling Data for 1- and 2-Bromopropane
STN Cushion Company
Thomasville, North Carolina
HETA 2000-0410-2891
November 14, 2000

Sample Location	Sample Time (min)	Sample Volume (L)	Concentration, ppm	
			1-BP	2-BP
In the middle of the Saw room	480	46.3	7.7	0.2
In the middle of the Fabrication room	478	47.0	7.2	0.11
In the middle of the Poly room	474	45.9	1.7	0.05
Minimum Detectable Concentration			**0.004**	**0.004**
Minimum Quantifiable Concentration			**0.02**	**0.01**

Table 5 – Full shift PBZ air sampling results for 1- and 2-BP
HETA 2000-0410-2891
STN Cushion Company, Thomasville, North Carolina
July 31 to August 2, 2001

Sample location	Concentration (ppm), 8-hr TWA									Average 1-BP exposure
	July 31			August 1			August 2			
	sample vol (L)	1-BP	2-BP	sample vol (L)	1-BP	2-BP	sample vol (L)	1-BP	2-BP	
Station #1	43.6	8.8	0.1							
Station #2	43.8	15	0.2	45.8	10.6	0.1	48.3	20.7	0.1	15.4
Station #3	43.4	15.1	0.1	48.6	14.2	0.1	47.4	24.8	0.2	18
Station #4	42.7	21.1	0.2	49.2	16.3	0.2	37.3	19.9	0.2	19.1
Station #5	34.6	14,7[1,]	0.2	44	16.11	0.2	46.7	23.8[1,2,3]	0.2	18.2
Station #6	35.9	31.9	0.3	30.1	17[W,1]	0.1	45.9	34.9	0.4	**27.9**
Station #7	35	16,5[1,]	0.1	44.9	17.3	0.2	47.3	15.3[1,2,3]	0.2	16.4
Station #8	31.1	13.91	0.1	32.5	17.5	0.1	45.3	14.3	0.2	15.2
Station #9	34.3	15.11	0.2	27.8	7.7	0.1	49.3	28.43	0.3	17
Station #10	34	11.8	0.1	42	21.81	0.2	23.7	17.8[2,3]	0.2	17
Station #11	33.8	15.81	0.2	44.4	29	0.2	47.4	32.71	0.3	**25.8**
Station #12	34	18,9[W]	0.2	45.3	17.81	0.2	46.5	24.1[1,3]	0.2	20.2
Mean		16.6	0.2		16.8	0.1		23.3	0.1	

Recommended exposure guideline			**1 ppm**
	25 ppm		**0.003**
Minimum Detectable Concentration		**0.003**	**0.009**

[1] *Stayed in Fabrication during morning break.*
[2] *Stayed in Fabrication during lunch break.*
[3] *Stayed in Fabrication during afternoon break.*
[W] *Station that periodically used water-based spray adhesive.*

Table 6
Short term (15 minute) PBZ air sampling results for 1- and 2-BP
HETA 2000-0410-2891
STN Cushion Company
Thomasville, North Carolina
July 31 to August 2, 2001

Sample location	Sample volume (L)	1-BP, ppm	2-BP, ppm
Station #2	3	8	Trace*
Station #3	3	16	0.2
Station #5	3.2	26	0.3
Station #6	3	47	0.4
Station #7	3	31	0.3
Station #8	3	7	Trace
Station #9	3	56	0.2
Station #10	3	40	0.4
Station #11	3	0.2	Trace
Station #12	3	25	0.2
Minimum Detectable Concentration		**0.05**	**0.04**
Minimum Quantifiable Concentration		**0.13**	**0.13**

** Trace concentrations fall between the MDC and the MQC.*

Table 7
Ceiling (5 minute) PBZ air sampling results for 1- and 2-BP
HETA 2000-0410-2891
STN Cushion Company
Thomasville, North Carolina
July 31 to August 2, 2001

Sample location	Sample vol. (L)	1-BP, ppm	2-BP, ppm
Station #2	1	32	ND*
Station #3	1.1	21	ND
Station #4	1	35	0.5
Station #5	1	26	ND
Station #6	1	ND	ND
Station #7	1	ND	ND
Station #8	1	ND	ND
Station #9 & 12**	1.1	ND	ND
Station #10	1.3	29	ND
Station #11	1	38	ND
Minimum Detectable Concentration		**0.14**	**0.12**
Minimum Quantifiable Concentration		**0.4**	**0.4**

* ND—*'Not Detected', concentrations are below the MDC.*
***Worker worked at both booths during this time.*

Table 8
Air sampling results from non-sprayers
HETA 2000-0410-2891
STN Cushion Company
Thomasville, North Carolina
July 31 to August 2, 2001

Sample type	Date	Location	Sample vol (L)	1-BP, ppm, 8-hr TWA	2-BP, ppm, 8-hr. TWA
PBZ [1]	37102	Shipping	36.1	5.8	0.1
PBZ	37102	Tick cutting	36	5.4	0.1
PBZ	37102	Sewing	36.1	5	0.1
PBZ	37102	Pattern room	35.9	4.6	0.1
PBZ	37102	Front office	36.5	4.2	0.1
GA [2]	37102	Outside on fence	19.5	0.01	ND*
GA	37102	Outside near fab. AC unit	22.6	0.01	ND
PBZ	37103	Poly cut	45.6	2.4	0.04
PBZ	37103	Feather room	11.8	1.1	0.03
GA	37103	Pattern room	48	5	0.09
PBZ	37103	Fabric cut	19.8	2	0.04
GA	37104	Fabrication doorway into Saw room	43.4	6.1	0.1
GA	37104	Poly cut	44.9	4.1	0.1
PBZ	37104	Sewing	47.2	5.2	0.1
PBZ	37104	Poly cut	47	3.8	0.1
GA	37104	Front office	44.9	3.1	0.1
GA	37104	I-beam in Poly cut	42.4	5	0.1
Minimum Detectable Concentration				**0.004**	**0.003**
Minimum Quantifiable Concentration				**0.011**	**0.011**

[1] PBZ—*Personal Breathing Zone.*
[2] GA—*General Area.*

* ND—*'Not Detected', concentrations are below the MDC.*

Table 9
Capture velocity and exhaust flow rate for Fabrication workstations (before enclosure).
HETA 2000-0410-2891
STN Cushion Company
Thomasville, North Carolina
April 18, 2001

Workstation number	Measured capture velocity at 3 ft[1] ft/min	Calculated Flow rate CFM[2]
1	6	231
2	N/V[3]	283
3	24	755
4	73	1545
5	37	546
A*	14	454
6	N/V	646
7	44	917
8	31	612
9	6	615
10	24	447
11	8	527
12	30	593
B*	26	564

[1] Value for workstation 6 is measured at a distance of 18 inches above the surface of the downdraft table.
[2] Cubic feet per minute.
[3] N/V—No data was available for this condition.
** These two booths removed before next evaluation, Table10.*

Table10
Average Spray Booth Ventilation Hood Face Velocity (after enclosure)
HETA 2000-0410-2891
STN Cushion Company
Thomasville, North Carolina
July 31 to August 2, 2001

Station #	# measurements used to average	Capture Velocity* w/doors open (ft/min)	Capture Velocity w/doors closed (ft/min)
1 & 2	28	57	70
3	20	30	50
4	20	34**	37
5	20	35	37
6	20	41	39
7	20	25	27**
8	20	17	24
9 & 10	28	26**	25
11	20	19	21
12	20	18	18

** Measured at 3 ft from the LEV hood.*
*** Indicates that measurements were only taken once, rather than twice as done for the other average values.*

Table 11
Characteristics of Study Participants Completing Questionnaire
HETA 2000-0410-2891
STN Cushion Company
Thomasville, North Carolina
July 31 to August 2, 2001

Characteristic	Participants in Exposed Group (N=12)	Participants in Comparison Group (N=18)
# (%) Female	12 (100%)	15 (83%)
Mean Age in Years (Range)	44 (29-65)	36 (21-55)
# (%) White	8 (67%)	16 (89%)
# (%) Black	4 (33%)	2 (11%)
Mean Length of Employment at STN in Months (Range)	13 (2-24)	21 (1-85)
# (%) Reporting Prescription Medication Use	6 (50%)	7 (39%)
# (%) Reporting Exposure to Other Substances of Concern[1]	2 (17%)	7 (39%)
# (%) Smoking Cigarettes[2]	5 (42%)	10 (56%)

[1] *Question asked if individual had any hobbies, household chores, part-time jobs or other activities that involve use of arsenic, mercury, lead, cadmium, solvents, pesticides or other chemicals.*

[2] *Individuals who responded "yes" to the question "Do you currently smoke cigarettes?"*

Table 12
Reported Symptoms and Odds Ratios Among 1-Bromopropane Exposed and Comparison Groups
HETA 2000-0410-2891
STN Cushion Company
Thomasville, North Carolina
July 31 to August 2, 2001

Symptom	# (%) of Participants Reporting Symptom - Exposed Group N=12	# (%) of Participants Reporting Symptom - Comparison Group N=18	Odds Ratio	95 % Confidence Interval Lower - Upper	
Anxiety, nervousness	2 (17%)	2 (11%)	1.78	0.21	14.86
Appetite increase	0 (0%)	2 (11%)	§	§	§
Appetite decrease	0 (0%)	0 (0%)	§	§	§
Blurred vision	6 (50%)	1 (6%)	16.00*	1.58	162.10
Trouble concentrating	1 (8%)	0 (0%)	§	§	§
Depression	3 (25%)	1 (6%)	6.00	0.54	67.28
Diarrhea	1 (8%)	1 (6%)	1.60	0.09	28.57
Dizziness; feeling “off balance”	6 (50%)	1 (6%)	15.00*	1.48	152.50
Felt drunk, “high,” “stoned”	1 (8%)	0 (0%)	1.10	0.91	1.33
Headache	7 (58%)	7 (39%)	2.00	0.45	8.96
Memory loss; forgetfulness	2 (17%)	2 (11%)	1.50	0.18	12.46
Nausea	4 (33%)	2 (11%)	3.75	0.56	25.12
Numbness or “pins and needles” feeling in hands	3 (25%)	3 (17%)	1.67	0.28	10.09
Numbness or “pins and needles” feeling in feet	4 (33%)	1 (6%)	9.71	0.92	103.04
Sleeping too much	2 (17%)	1 (6%)	3.78	0.30	47.56
Trouble falling asleep or staying asleep	5 (42%)	3 (17%)	4.17	0.75	23.18
Tremor or shakiness	2 (17%)	1 (6%)	4.25	0.33	54.07
Weakness/clumsiness in hands	1 (8%)	2 (11%)	0.80	0.06	10.01
Problems with hand writing	1 (8%)	1 (6%)	1.70	0.10	30.28
Weakness in arms	3 (25%)	3 (17%)	1.88	0.31	11.52
Weakness in feet	2 (17%)	0 (0%)	1.22	0.93	1.62
Weakness in legs	3 (25%)	1 (6%)	6.38	0.57	71.27
Walking problems	1 (8%)	0 (0%)	1.10	0.91	1.33
Weight loss	1 (8%)	1 (6%)	1.70	0.10	30.28

§ *One or more of the contingency table counts was equal to zero.*

** Asterisks indicate a significant difference from the comparison group (*p<0.05.)*

Table 13
Urine Bromine Analysis Of 1-Bromopropane Exposed and Comparison Groups
HETA 2000-0410-2891
STN Cushion Company
Thomasville, North Carolina
July 31 to August 2, 2001

Measure (Matched Pair)	**Population**	**Number Subjects**	**Geometric Mean[1]**	**Minimum Value[1]**	**Maximum Value[1]**	**Probability** (p value)
Start-of-week Urine Bromine Concentration	Exposed	7	6.4	1.8	14.0	0.005*
	Comparison	10	1.9	1	3.5	
End-of-week Urine Bromine Concentration	Exposed	7	7.7	2.5	38.0	0.003*
	Comparison	12	2	0.8	6.2	
Post Minus Pre-Exposure Concentration (Difference)	Exposed	6	-0.42	-3	3.1	0.710[3]
	Comparison	10	0.1[2]	-1.3	3.6	0.917[3]

[1] *Concentration is reported in milligrams per liter.*
[2] *Value is arithmetic mean (Geometric mean can not evaluate negative numeric data.)*
[3] *Test Value = 0, H_o: mean of sample = 0 (For exposed group expect mean to be > 0, for comparison group expect mean to be = 0.)*
** Asterisks indicate a significant difference from the comparison group (*p<0.05.)*

Table 14
Neurobehavioral Test Parameter Analysis Of 1-Bromopropane Exposed and Comparison Groups
HETA 2000-0410-2891
STN Cushion Company
Thomasville, North Carolina
July 31 to August 2, 2001

Measure	Population	Number Subjects	Mean	Minimum Value	Maximum Value	Probability (p value)
Tremor Pen Right – Intensity (meter/second^2)	Exposed	12	0.14	0.10	0.22	0.033*
	Comparison	18	0.11	0.06	0.16	
Tremor Pen Right – Frequency (Hertz)	Exposed	12	7.5	5.7	8.8	0.001*
	Comparison	18	6.3	4.5	8.8	
Tremor Pen Right – Harmonic Index	Exposed	12	0.92	0.85	0.99	0.717
	Comparison	18	0.92	0.85	0.98	
Tremor Pen Left – Intensity (meter/second^2)	Exposed	12	0.11	0.07	0.19	0.241
	Comparison	18	0.10	0.06	0.16	
Tremor Pen Left – Frequency (Hertz)	Exposed	12	6.5	4.4	9.2	0.882
	Comparison	18	6.4	4.7	8.4	
Tremor Pen Left – Harmonic Index	Exposed	12	0.90	0.87	0.95	0.100
	Comparison	18	0.88	0.79	0.98	
Reaction Time – Mean	Exposed	12	0.264	0.183	0.354	0.415
	Comparison	18	0.248	0.189	0.310	
Reaction Time – Standard Deviation	Exposed	12	0.048	0.020	0.090	0.917
	Comparison	18	0.049	0.029	0.105	
Slow RF[1] Finger Tap – Mean	Exposed	12	-0.056[3]	-0.158	0.022	0.253
	Comparison	18	-0.071[3]	-0.164	0.027	
Slow RF[1] Finger Tap – Standard Deviation	Exposed	12	0.059	0.018	0.114	0.015*
	Comparison	18	0.044	0.029	0.096	

Table 14 (Continued)
Neurobehavioral Test Parameter Analysis Of 1-Bromopropane Exposed and Comparison Groups
HETA 2000-0410-2891
STN Cushion Company
Thomasville, North Carolina
July 31 to August 2, 2001

Measure	Population	Number Subjects	Mean	Minimum Value	Maximum Value	Probability
Fast RF[1] Finger Tap – Mean	Exposed	12	-0.060[3]	-0.154	-0.001	0.755
	Comparison	18	-0.051[3]	-0.139	0.014	
Fast RF[1] Finger Tap – Standard Deviation	Exposed	12	0.047	0.008	0.115	0.062
	Comparison	18	0.029	0.016	0.131	
Maximum Frequency Finger Tap	Exposed	12	5.0	1.6	7.5	0.819
	Comparison	18	5.2	3.2	7.5	
Slow P/S[2] RF[1] – Mean	Exposed	12	-0.065[3]	-0.138	0.004	0.692
	Comparison	18	-0.066[3]	-0.149	0.077	
Slow P/S[2] RF[1] – Standard Deviation	Exposed	12	0.066	0.032	0.155	0.602
	Comparison	18	0.056	0.032	0.136	
Maximum Frequency P/S[2]	Exposed	12	3.7	2.5	6.0	0.491
	Comparison	18	3.2	1.0	4.9	

[1] *Rhythmic Frequency*.
[2] *Pronation/Supination*.
[3] *Value is arithmetic mean (Geometric mean can not evaluate negative numeric data.)*
* *Asterisks indicate a significant difference from the comparison group (*p<0.05.)*

APPENDIX

Brominated Solvents Background and Significance

In 1990 the Clean Air Act (CAA) was amended to include more stringent provisions for the protection of stratospheric ozone and the phase-out of several ozone-depleting substances under Title VI of the law.[1] The law targeted the complete phase-out of several substances including chlorofluorocarbons, hydrochlorofluorocarbons, and methyl chloroform, each of which was being used by industry at that time. Industrial applications of these substances included non-aerosol solvent cleaning, adhesive coatings applications, and solvent applications.[2] The CAA amendment provisions were in part enacted to abide by the terms of a United Nations (UN) international agreement, The Montreal Protocol on Substances that Deplete the Ozone Layer adopted in 1987, which committed to reduce and eventually eliminate the use of ozone-depleting substances. As a result, several countries discontinued and prohibited further use of ozone-depleting substances.[3] Under Section 612 of the CAA, ozone-depleting substances were to be replaced with alternative substances or processes that reduced the risks to human health and the environment.[1] To fulfill the law's requirement, the Environmental Protection Agency (EPA) initiated the Significant New Alternatives Policy (SNAP) program intended to approve safe alternatives for ozone-depleting substances.[4]

The solvents 1-bromopropane (1-BP) and 2-bromopropane (2-BP) were introduced into workplaces around the world as substitutes for ozone-depleting substances following initiation of the 1987 UN international treaty. The physical properties of these two solvents, including high volatility and low flammability, were seen as favorable characteristics for a non-aerosol solvent. Due to photochemical breakdown, the solvents have a relatively short atmospheric half-life (17.5 to 24 days), possibly decreasing their ozone-damaging capacity.[5,6]

At the present time, 2-BP is not produced for commercial use in the United States (U.S.). However, 1-BP is produced and commercially available in the U.S. The purity of 1-BP is listed as 99% in Material Safety Data Sheets (MSDS) from two laboratory reagent manufacturers.[7,8] A 1999 Occupational Safety and Health Administration (OSHA) analysis of several commercial samples of 1-BP found them to contain 2-BP in concentrations ranging from 0.1 to 0.2 percent.[9] A voluntary consensus standard (D6368-00) published by the American Society For Testing and Materials has since been released covering vapor degreasing and general grade 1-BP and specifies that the content of 2-BP in these solvent grades remain below 0.1 percent.[10] Currently only 1-BP is being reviewed under the SNAP program as a potential alternative to ozone-depleting substances.[2] At this time, the EPA has not disapproved the use of 1-BP, so it may be used for any purpose in the U.S. (while 2-BP may not).[9]

Review of Literature— 1-Bromopropane

Animal exposure studies have demonstrated reproductive toxicity for both male and female rats when exposed to concentrations greater than or equal to 200 parts per million (ppm) of 1-BP.[11,12] Two studies noted mild hepatic

changes in rats exposed to greater than or equal to 800 ppm of 1-BP; these changes were considered adaptive and reversible due to the absence of other signs of hepatotoxicity.[11,13,14] Although 2-BP exposure has been associated with pancytopenia, animal studies evaluating potential hematopoietic effects of 1-BP exposure have yielded no firm conclusions. The median lethal inhalation concentration of 1-BP for Sprague-Dawley rats has been estimated to be 14,374 ppm.[13]

Four studies have demonstrated some form of neurotoxicity in rats exposed to 1-BP. All studies involved exposure concentrations greater than or equal to 800 ppm. Three of the studies demonstrated decreased peripheral nerve functioning by electrophysiologic testing and morphologic or histopathologic abnormalities of central and peripheral nerves.[15,16,17] Two of these three studies also demonstrated a prominent weakness of the hind limbs following exposure.[15,17] A fourth study demonstrated decreased peripheral nerve functioning by electrophysiologic testing alone.[18] One of the five studies established that the muscle weakness and decreased electrophysiologic findings were both dependent on concentration and length of exposure period.[17] This same study and one other came to the conclusion that 1-BP was a more potent neurotoxicant than 2-BP; another study that evaluated the neurotoxicity of both 1-BP and 2-BP was unable to conclude that 1-BP was a more potent neurotoxicant.[15,18]

A total of four persons with health effects considered related to 1-BP exposure have been described in two published case reports. The first case report concerned a 19-year-old male working as a metal 'stripper'.[19] He was exposed on a daily basis over a two-month period to an industrial solvent (containing greater than 95.5 percent 1-BP by weight) used for degreasing and cleaning. His right hand was most commonly exposed to the solvent. The air concentration of 1-BP and type of ventilation were not discussed in the article. Presenting symptoms included "numbness and mild but progressive weakness of the proximal lower extremities and the right hand… transient dysphagia and urinary difficulties."[19] The physical findings, magnetic resonance imaging (MRI) of the brain, and electromyography (EMG) findings supported the diagnosis of a "primary demyelinating condition, predominantly affecting the lower extremities, in the distribution of an acquired neuropathy, but with evidence of central nervous system involvement as well." The EMG did not indicate any evidence of muscle denervation. The individual did demonstrate improvement following removal from exposure, but was lost to follow-up before it was determined if the health effects would fully resolve.

The second case report concerned three females, ages 35, 30, and 50, each working at cushion manufacturing companies in North Carolina.[20] The workers sprayed glue (containing 55 percent 1-BP as the base solvent) with a spray gun onto polyurethane foam pieces. A total of 15 workers performed this process in an open work area. Exhaust ventilation provided at each workstation was operated intermittently and workers wore latex gloves for dermal exposure protection. The first worker's symptoms developed one year following the replacement of a dichloromethane-based glue with the 1-BP-based glue. The remaining two workers developed symptoms six months and two months, respectively, following commencement of their employment in the exposure area. Airborne exposures of the three workers were not well described; the case report

did state that one worker was found to have time-weighted average (TWA) exposures of between 60 to 261 ppm of 1-BP over several days of monitoring 5 months after symptoms had started.

"The three workers showed the common symptoms of staggering, numbness and paresthesia/dysesthesia with a similar distribution in their feet, legs, thighs, lower back and hips as well as a remarkable decrease in vibration sense, along with various symptoms of the central nervous system and autonomic symptoms."[20]

Other symptoms experienced by the workers included temporary menstrual cycle disruption for two of the three women, diarrhea, abnormal sweating, and urinary incontinence. The researchers concluded that 1-BP likely caused the peripheral and central nervous system deficits and that the other noted symptoms were likely related to autonomic system disruption secondary to 1-BP exposure. The study did not indicate if the symptoms improved or resolved upon removal from exposure.

Limited information is available from an unpublished abstract submitted at the 2002 Annual Meeting of the Society of Toxicology regarding the only 1-BP human health effect study performed to date.[21] The study evaluated a group of 25 female workers, exposed to low levels of 1-BP, for neurological effects, comparing them to a group of 27 unexposed controls. Neurobehavioral and electrophysiological assessments of nerve function were performed on both groups. Because of the limited nature of the information presented in this abstract, it is difficult to draw conclusions from this study.

Review of Literature—2-Bromopropane

Following report of the occurrence of secondary amenorrhea among female workers in a tactile switch assembly section of a South Korean factory, two studies were performed to evaluate the health effects of workers in the factory.[22,23] The studies found background area air sample concentrations of 2-BP to range from 9.2 to 19.6 ppm. The concentration of 2-BP detected during a short-term sample inside the hood of a cleaning bath was 4,140.7 ppm. One study theorized that workers might be exposed to higher concentrations of 2-BP for short periods of time when performing operations at the cleaning bath.[22] The other study theorized that because there were two uncovered 2-BP baths in the area and ventilated air was recirculated, 2-BP concentrations were routinely elevated in the work area.[23] Both studies concluded that 2-BP exposure was the probable cause of the health effects (ovarian failure in females, azoospermia or oligospermia in males, and pancytopenia) noted in the exposed workers.

Following these reports, several studies designed to evaluate health effects associated with exposure of rats to 2-BP were initiated; these studies demonstrated ovarian, testicular, and hematopoietic dysfunction beginning at exposure levels of greater than 300 ppm or 250 milligram per kilogram (mg/kg).[24,25,26,27,28] Two studies recently demonstrated peripheral neurotoxic changes and peripheral neuropathy in rats exposed to 1,000 ppm of 2-BP.[18,29] The median lethal inhalation concentration of 2-BP for the Sprague-Dawley rat has been estimated to be 31,171 ppm.[30]

One study has been conducted to evaluate the health effects of 2-BP on employees working at a 2-BP manufacturing plant. During the study, conducted in 1996, worker breathing zone exposure concentrations ranged from 0.80 to 16.18 ppm as an 8-hour TWA. The study included worker interviews, medical examinations, and specific testing of reproductive and hematological indices. "No severe cases of reproductive or hematopoietic disorders were found at (exposures) less than 10 ppm (TWA), but a possible adverse effect of 2-bromopropane on hematopoiesis could not be disproved."[31]

1-Bromopropane Biomarker of Exposure

A study has demonstrated that among seven different solvents, 1-BP was the only solvent that significantly ($p < 0.01$) influenced the concentration of 1-BP and bromine in the urine of exposed subjects, and thus either measure can be used as a biomarker of exposure.[32] In that study, 1-BP concentration in the urine was shown to be more highly correlated to the airborne 1-BP exposure ($p < 0.01$, $r = 0.952$) than was bromine concentration in the urine ($p < 0.01$, $r = 0.738$). However, urinary 1-BP detection requires gas chromatography-mass spectrometry (GCMS) instrumentation and the specimen must be immediately analyzed after collection. Most clinical laboratories can perform bromine detection, and analysis may be delayed without serious degradation of specimen quality. Cost constraints would be the main reason why bromine analysis might be chosen over GCMS analysis in a study.

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